AGROFORESTRY, GRASS, BIOMASS CROP, AND ROW-CROP MANAGEMENT EFFECTS ON SOIL WATER DYNAMICS FOR CLAYPAN LANDSCAPES

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Abstract

Soil water use and water storage varies by vegetative management practice and these practices affect land productivity and hydrologic processes. This study investigated the effects of perennial vegetative management systems of agroforestry buffers, grass buffers, and biomass crops, relative to row crop management on water use for a claypan soil in northern Missouri, USA. Results showed significant differences in weekly soil water content among treatments for all four soil depths. Soil water content decreased more rapidly during the summer in agroforestry buffers, grass buffers, and biomass crops compared with the row crop treatment. During recharge periods, a larger increase in soil water content due to better infiltration was observed in the perennial vegetative management practices relative to row crop areas; this can be attributed to enhanced soil pore characteristics (macroporosity) due to changes in soil carbon in agroforestry, grass, and biomass areas. The results showed that vegetative management practices can significantly influence soil water use and storage compared to row crop areas, particularly for eroded claypan landscapes, and these findings can be used to address challenges of soil and water conservation.

Keywords: soil water use; vegetative management practice; claypan soil; recharge periods

Introduction

Vegetative management approaches can help to improve water storage and to reduce transport through the soil profile; these changes can reduce nutrient and pesticide runoff for enhanced sustainable agricultural production (Bharati et al. 2002). A study conducted by Anderson et al. (2009) found that that agroforestry buffers contributed to reduced soil water content compared with row crop areas. Agroforestry practices have also increased water infiltration rates and storage. On the same watersheds, Sahin et al. (2016) showed that agroforestry buffers had lower soil water content than row crop areas during the summer season; however, the infiltration rate was higher within agroforestry buffer practices relative to row crop areas during water recharge periods. Increased water storage under agroforestry and grass buffers has contributed to reductions in surface runoff from row crop areas (Udawatta et al. 2011a). In addition, agroforestry buffers can reduce soil water through enhanced water consumption, and this reduced soil water content will improve water infiltration and may decrease surface runoff, nutrient, and pesticide losses. However, a good understanding of water use within the soil profile is needed to improve water use efficiency under management practices and to design sustainable management practices including agroforestry buffer strips and biomass crops (Anderson et al. 2009; Mulebeke et al. 2010). The objective of this study was to quantify water use, recharge, and storage by perennial vegetative practices and row crops for a claypan soil in northern Missouri, USA.

Materials and methods

The experimental site with three adjacent north-facing watersheds (West, Center, and East) was located at the University of Missouri Greenley Memorial Research Center, Novelty, Knox County, Missouri, USA (Figure 1). Agroforestry buffer (AB), grass buffer (GB), and row crop (RC) treatments were randomly assigned to the watersheds in 1997. The GB (West) and AB (Center) watersheds consisted of 4.5-m wide buffer strips at 36.5-m spacing. The areas between buffers were planted to a corn–soybean rotation with a no-till practice beginning in 1991. In the GB and AB watersheds, birdsfoot trefoil, brome grass, and redtop were planted with pin oak trees, swamp white oak trees, and bur oak trees planted at 3-m apart down the center of the grass-legume strips of the AB watershed in 1997. Biomass crop (BC) was a switchgrass and winter peas mixture which replaced the RC areas in the West and Center watersheds in 2012 between buffers. The dominant soil in this study area was mapped as Putnam silt loam, and it has a drainage restrictive B horizon with a claypan soil. The 30-year average annual precipitation of the experimental site is 920 mm, of which more than 66% falls from April through September.

Volumetric soil water (VSW) content was determined by Campbell CS-616 (Campbell Scientific Inc, Logan, UT) sensors installed at 5-, 10-, 20-, and 40-cm depths with three replications. Sensors were connected to an AM16/32 multiplexer and the multiplexer was connected to a CR23X-4m data logger to record VSW at 10-min intervals (Udawatta et al. 2011b) from the middle of April 2017 to November 2017. VSW were extracted from the datalogger at 12:00 noon each Friday. Sensor readings were calibrated for VSW by regular gravimetric water content determinations and Equation (1) from Udawatta et al. (2011b).

$$\theta v = -0.311 + 0.0193 \times r \qquad (1)$$

Where:

θv: Volumetric water content

r: Period of the signal.

The General Linear Model (GLM) and least significant differences (Duncan's LSD) (P<0.05) procedures in SAS determined statistical significance for VSW among treatments, soil depths, and treatment by depth interactions (SAS Institute 2013).

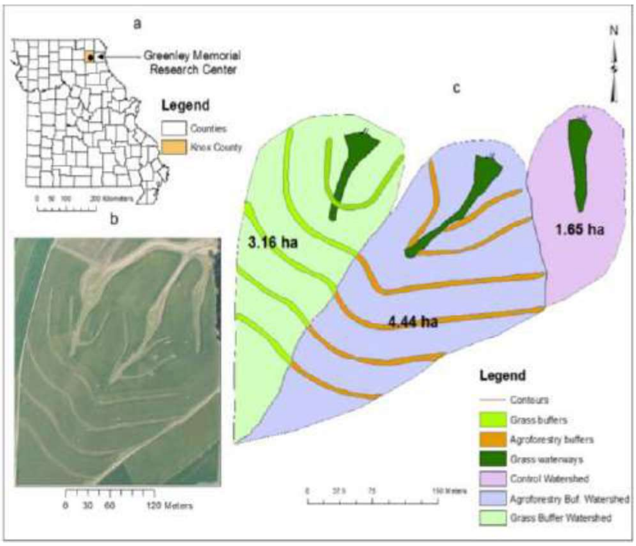

Figure 1: (a) Location of the study site in Missouri, USA (b) Aerial view, and (c) land management maps for the GB (West watershed), AB (Central watershed) and RC (corn-soybean rotation, East watershed) watersheds. All three watersheds have grass waterways at the downslope. Areas between the grass and agroforestry buffers are managed with biomass crops since 2012.

Results and discussion

Significant differences ($P<0.05$) among VWC were found by vegetative management practices, sampling depth, and the interactions between treatment and soil depth. Significant differences also occurred for the three contrasts: ‘RC vs others’, ‘buffers vs BC’, and ‘GB vs AB’.

Higher VWC occurred during most weeks after May 5 for AB, BC, and RC treatments compared to the GB. Lower VWC occurred during three summer drawdown periods for the AB, GB, and BC treatments compared to the RC; these periods included (i) 2-9 June, (ii) 7 July to 18 August, and (iii) 1-29 September. Soil water content was higher for the RC management compared to AB, GB, and BC treatments in these periods due to more water use by trees, grass, and switchgrass (Anderson et al. 2009). Also, this decrease in VWC for the perennial vegetation may help to reduce nutrient and sediment runoff during subsequent rainfall events after these drawdown periods as well as improve water recharge in the soil profile.

Precipitation events of 50, 92, and 83 mm on 16-17 June, 21-22 August, and 5-6 October, respectively, recharged soil water content, with greater increases in VWC in the buffer and biomass treatments (Figure 2). Higher water content in the perennial management treatments relative to RC can be attributed to better root systems which were created by AB, GB, and BC compared to the annual RC root system (Udawatta et al. 2011a; Zaibon et al. 2017). The BC and RC treatments had higher VWC compared to buffer treatments from 13 October to 17 November, but there were no significant differences among the treatments.

VWC was significantly different among soil depths averaged across the treatments. For 5 cm depth, average soil water content readings ranged from 0.46 $m^3\ m^{-3}$ on 14 April to a low of 0.29 $m^3\ m^{-3}$ on 9 June, from 0.50 $m^3\ m^{-3}$ on 30 June to a low of 0.25 $m^3\ m^{-3}$ on 18 August, and from 0.38 $m^3\ m^{-3}$ on 1 September to a low of 0.24 $m^3\ m^{-3}$ on 29 September. After recharge, VWC values changed to 0.45, 0.42, and 0.45 $m^3\ m^{-3}$ on 16 June, 25 August, and 6 October, respectively. Average water content for 10 cm depth followed a similar pattern as the 5 cm depth, but higher water content values occurred within this depth. Generally, the lower and higher water content values pre- and post-recharge periods in the buffers and biomass crops may be attributed to higher root density and greater root decay at the surface (0 – 10 cm). These root system effects improve soil structure by creating deeper root systems which increase the proportion of macropores and add organic matter, and subsequently reduce surface runoff particularly in claypan landscapes (Rachman et al. 2004; Kumar et al. 2008; Zaibon et al. 2017). Also, these researchers have reported that below the 0 – 10 cm depth, the influence of root systems begins to decrease. For the 40 cm sampling depth, water content values were the highest compared to the 5, 10, and 20 soil depths except on 14 April, 28 April, 5 May, 26 May, 16 June, and 30 June. This was probably because bulk density for the 40 soil depth was lower than other depths due to an increase in clay content and subsequent swelling of clays through these subsoil horizons.

Three principle recharge periods occurred on 15 June, 24 August, and 5 October. The water content values in the AB, GB, and BC increased more after recharge periods compared to values for the row crop treatment (Figure 2). These higher water content values in the buffer and biomass treatments were probably due to the long-term perennial vegetative management. These perennial systems have an improved macroporosity which helps water better infiltrate into the soil (Anderson et al. 2009; Sahin et al. 2016). Interestingly, AB, GB, and BC had lower water content in the pre-recharge periods compared to the row crop treatment, but equal or sometimes slightly higher water content in the immediate post-recharge periods compared to the row crop treatment. This was probably due to higher transpiration and more water depletion by trees, grasses, and biomass treatments relative to row crops (Anderson et al. 2009). However, as trees mature root pruning, removing branches, and thinning may be needed to reduce the competition for resources (Senaviratne 2012).

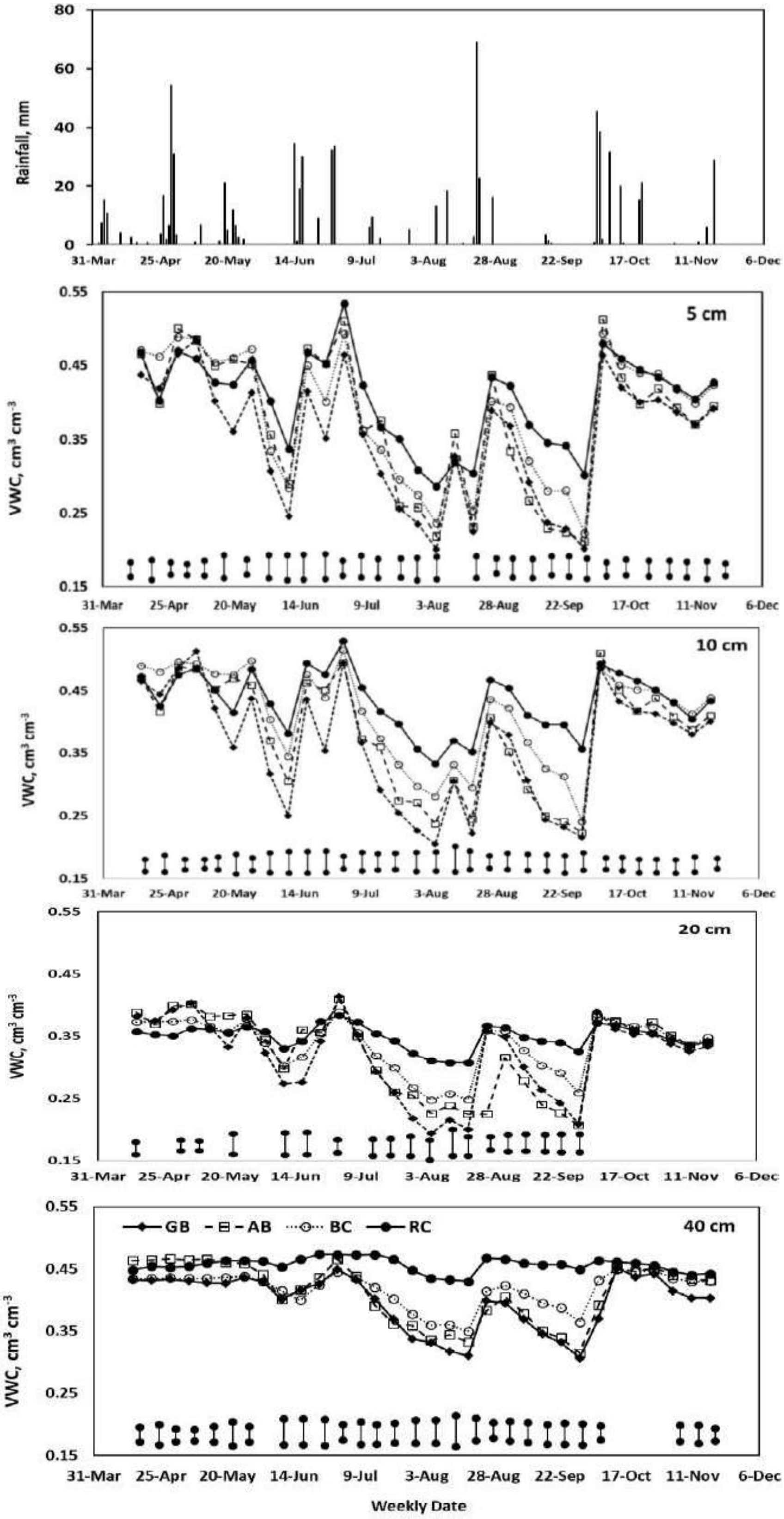

Figure 2: Rainfall distribution and effects of buffer treatments on VWC detected at 12:00 pm each week at 5 cm, 10 cm, 20 cm, and 40 cm depths. Bars indicate the least significant difference.

Conclusion

Results of this study showed that greater profile recharge and more water storage occurred in soils of perennial vegetative areas compared to the row crop management during recharge periods. The lower antecedent soil water content found in the buffer and biomass treatments during pre-recharge periods and the subsequent increased water infiltration and profile recharge during rainfall events will probably reduce surface runoff and soil loss under these perennial vegetative management practices relative to grain crop production. Establishment of agroforestry buffers and biomass crops on strategic locations within row crop watersheds may help reduce non-point source pollution from row crop agriculture. In addition, planting perennial vegetation systems such as trees and grasses may improve soil health parameters and selection of appropriate cultural practices such as selection of soil-site-climate suitable trees and grasses could further enhance water quality benefits and other ecosystem services.

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